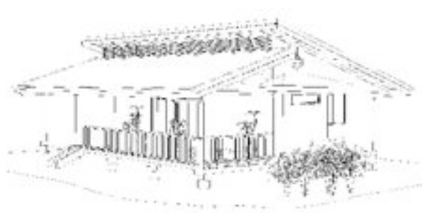
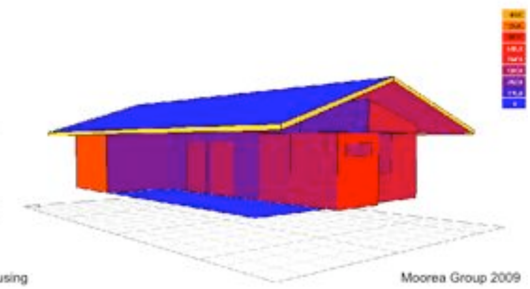
Bioclimatic Kit House

Moorea, French Polynesia



Office of Polynesian Housing



Moorea Group 2009

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Presentation Outline

1. Problem Overview
2. Project Goals
3. Obstacles and Assumptions
4. Approach: Ecotect
5. Information Limitation
6. Technology Suggestions: Gossamer Fan Blade & Infrared Reflective Paint
7. Ecotect Framework & Analysis Results
8. Future Project Plans
9. Concluding Thoughts & Reflections

The Problem

The kit house is an affordable, typhoon resistant housing option in French Polynesia, but is currently uninhabitable during the day due to high temperatures

Problem Outline

1983- Cyclone Veena destroyed many homes on islands

- Kit house developed and imported
- User Needs: cheap, easy to construct and typhoon resistant

1992-Typhoon William

- Kit houses were the only standing homes
- Houses sold commercially & distributed, yet too hot during the day (37° C =98°F)

2004- Kit Houses are the affordable housing option

- Average income/yr = $18,000 (CIA) vs. Average home cost = $600,000
- Government gives land to natives or family owns vs property and land value

2006-Thermal analysis and design suggestions for 3rd prototype (ER291)

- 3rd prototype never distributed

2009-Improvements made, designed a 4th prototype

- Analyzing 4th prototype before distribution, project proposal for onsite research

Goals

Overarching Goal

- Increase thermal comfort and affordability of kit house to adequate level for the standards of those living in French Polynesia

Immediate Goals

- Digital model of 4th prototype to enable easy manipulation of design features affecting thermal properties
- Generate analysis in relation to thermal comfort
- Make suggestions to improve thermal qualities of kit house
  - **Balancing comfort and affordability**
- Influence Office of Polynesian Housing's (OPH) housing design methods
- Future project proposal and summer research
  - Test-run hobo sensors
  - Show OPH Building Information Modeling Software
  - Analyzing/testing kit house onsite

Approach: Obstacles and Assumptions

Indirect Communication Source

Madelaine Fava:

- Designed original kit house, no longer project architect

Office of Polynesian Housing (OPH):

- Controls and administers kit house design
- Government agency: Indirect contact through Madelaine
- Communication lag, shortage in needed information
- Working with government = GRADUAL PROCESS
- Assumptions made that could affect accuracy of thermal analysis

Moorea Group ⇄ Madelaine ⇄ OPH

CA, USA

France

French Polynesia

Approach: Obstacles and Assumptions

Kit House Design Details

Givens:

- Plans (no sections), perspective drawing, 54 pgs of framing details

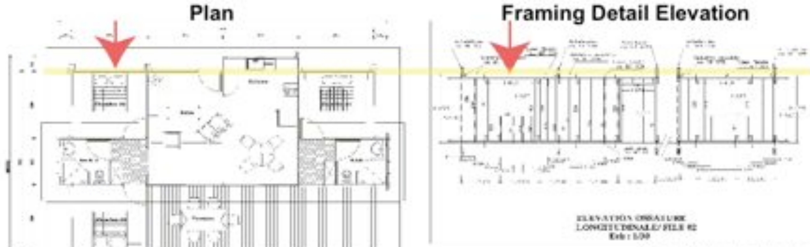
Discrepancies:

- Window placement, roof structure and insulation specifics

Assumptions:

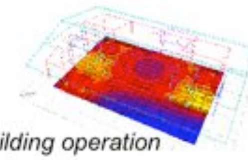
- Autocad Drawings: Details compiled through extruding construction lines
- Roof Width/ Height: used construction lines from CAD
- Window Placement: kept consistent with plan

Plan **Framing Detail Elevation**



Office of Polynesian Housing

Approach: Ecotect



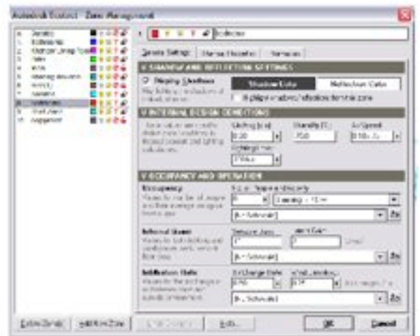
Ecotect is a 3D Modeling program that provides analysis on building operation and performance to create energy efficient and sustainable designs.

Use Value

- Analyze existing conditions of house
  - Interior Temperature & Air Movement → *Thermal Comfort*
- Use model to easily change building features to test design improvements
- Successful Design: Decreases interior temperature & Increases Air Movement

Inputs

- Weather Data from Singapore
- Latitude & Longitude of Moorea
- Northeast House Orientation (varies)
- Zone Properties
  - Internal gains, Humidity, Activity, Clo, Occupancy, ACH
  - Field Notes 2006 Moorea Group
- Material Properties



Ecotect Model 2009

Approach: Ecotect & Information Limitations

Ecotect Limitations

Software Learning Curve

Roof Vent

- Cannot accurately model roof vent effect (need data from design)
- Qualitative assumptions about roof function
- Airflow effects thermal comfort

Information Limitations

- Inconsistencies/ Errors in Kit House Design Details
- These details will affect model predictions

Research Strategies in Response to Limitations

1. Focus on kit house design features that PEOPLE control, rather than just OPH
2. Continue work with OPH, more information gathered onsite
3. Focus on relationships of Ecotect model predictions

Approach: Ecotect & Information Limitations

1. **Reality**: Many people currently paint roofs dark green/red = Increase internal temp

    Question: Color of roof is cultural preference, so how can we work within that framework?

    Response: Multi- color/ Clear gloss Infrared Reflective Paint

2. **Reality:** Air Movement increases thermal comfort

    Question: How can we increase air movement besides natural ventilation?

    Response: Fan with Gossamer Blade Technology (Low Energy)

Insultec.com

Gossamerwind.com

Approach: Near Infrared Reflective Paint

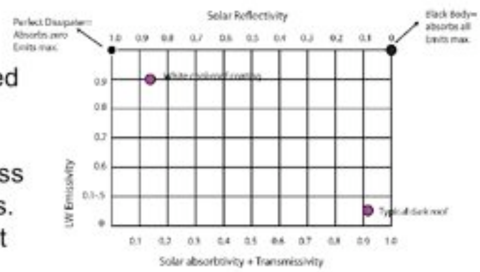
High Solar Reflectance (Paint ↑ Reflectance) + High Emissivity (Unpainted Metal Roof = Low E) = Low Surface Temp **= COOLER Interior Temp!**

Current Condition:

- Metal roof: heat absorption between 25% (light)-80%(dark)
- Heat Absorption dependent on roof color, darker = ↑ absorption

Desired Condition:

- Roof with infrared reflective paint
- Roof paint coated with near infrared reflective clear gloss
- Metal roof with infrared reflective paints = heat absorptions rate of less than 15% for a wide range of colors.
- Reflectance =less color dependent



Approach: Fan -Gossamer Blade Technology

Aerodynamic blade shape increases air movement without increasing energy use.

Current Cost vs. Improved Technology Cost

		Quanti ty	All on (hrs/day)	One on (hrs/day)	Watt s	$/kWh	Cost/day	Cost/year	Saved (40%)
LIGHTS	Max	5	8.5	7	60	0.375	1.11	406.52	162.61
	Min	5	4	11.5	60	0.375	0.71	258.69	103.48
FANS	Max	5	8	0	50	0.375	0.75	273.75	109.50
	Min	5	2	0	50	0.375	0.19	68.44	27.38
						$ SAVED/ YEAR		Max Saved:	272.11
								Min Saved:	130.85

Increased Comfort & Cost Savings!

**Assuming 1 fan in each room, two fans in kitchen/living space,and information from Madelaine Fava

Parker, Danny S., Michael P. Callahan, Jeffrey K. Sonne, and Guan H. Su. Development of a High Efficiency Ceiling Fan "The Gossamer Wind" Publication. 2007. Florida Solar Energy Center.

Approach: Ecotect Analysis Framework

Analyzing Interior Temp & Air Movements Impact on Thermal Comfort

Comfort Model

- USA Temp tolerance is lower than people in French Polynesia
- Changed comfort band to 26-32 °C

Current Conditions

- Dark Roof: Low reflectance, high absorbtivity= HOT!
- Minimal air movement

Testing Scenarios

1. Required Air Velocity of Current Condition(Assume no air movement)
2. % of Time Discomfort Over Month
3. Current condition vs. Air Movement (Fan)
    - Hottest day vs Coolest day
    - (Air Movement Defined by ACH: 1 Fan/bedroom & 2 in Living Room)

Issue: Method of testing Infrared Reflective Paint in Ecotect Model to see affect on thermal comfort did not work!

Approach: Ecotect Kit House

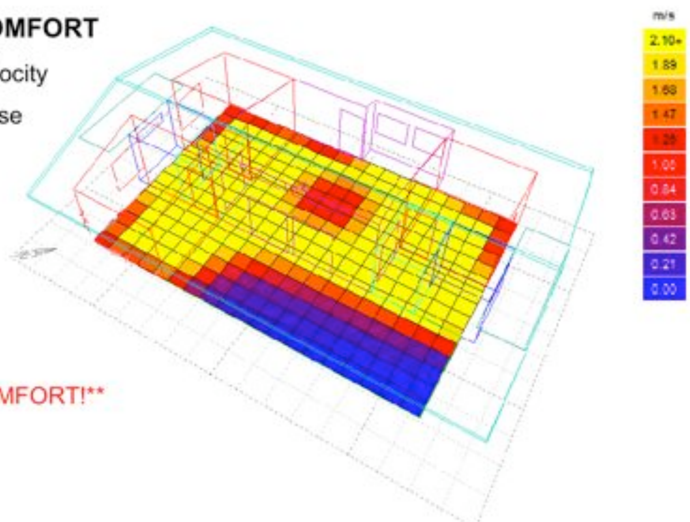
Focus = Bedrooms & Living Room/ Kitchen

Results: Required Air Velocity

THERMAL COMFORT

Required Air Velocity

**current kit house conditions



Focus on COMFORT!

Kit house needs air movement! We know this…

Results: Ecotect % Discomfort Over Month

DISCOMFORT DEGREE HOURS
Comfort Band: 26-32°C

CURRENT CONDITION
(Assuming No Air Movement)

MONTH	TOO HOT (%)	TOO COOL (%)	TOTAL (%)
Jan	4.03	0.00	4.03
Feb	8.82	0.00	8.82
Mar	14.01	0.00	14.01
Apr	21.70	0.00	21.70
May	17.81	0.00	17.81
Jun	19.17	0.00	19.17
Jul	13.27	0.00	13.27
Aug	12.87	0.00	12.87
Sep	9.27	0.00	9.27
Oct	11.49	0.00	11.49
Nov	6.88	0.00	6.88
Dec	3.86	0.00	3.86
TOTAL	143.2	0.0	143.2

=ALWAYS TOO HOT!

WITH AIR MOVEMENT
(Based on ACH of Fan)

MONTH	TOO HOT (%)	TOO COOL (%)	TOTAL (%)
Jan	0.60	9.31	9.91
Feb	1.64	2.12	3.76
Mar	5.81	1.24	7.06
Apr	12.12	1.04	13.16
May	5.91	0.87	6.79
Jun	7.53	1.11	8.65
Jul	3.49	4.54	8.03
Aug	3.73	2.49	6.22
Sep	2.74	5.03	7.78
Oct	2.99	2.72	5.71
Nov	1.70	7.01	8.72
Dec	0.17	10.22	10.38
TOTAL	48.4	47.7	96.2

House with Air Movement = 67% Less Discomfort/ Year

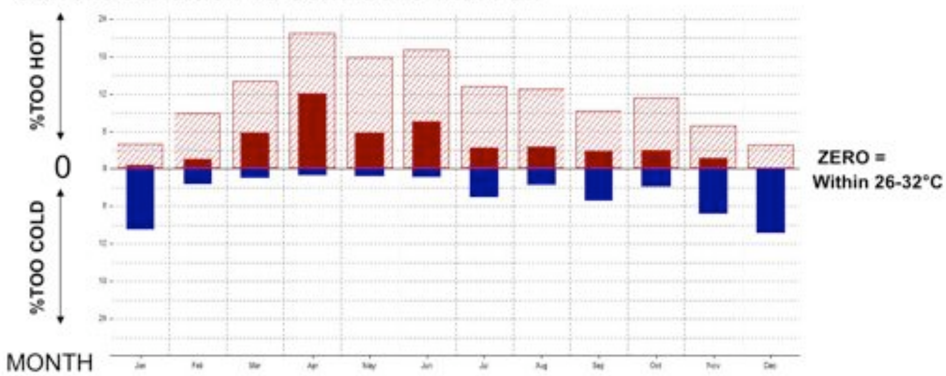
Results: Ecotect % Discomfort Over Month

Goal: To reduce range of discomfort by nearing zero (increasing air movement)

**Too cold = turn fan off
**Deviation from ZERO = Beyond Comfort Range 26-32°C

Current Condition
Fan: Too Hot
Fan: Too Cold

Current Condition vs Conditions with Fan

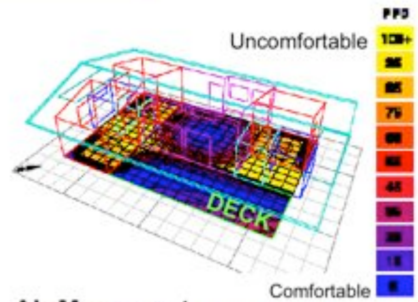


Results: % Dissatisfaction-Hottest Day

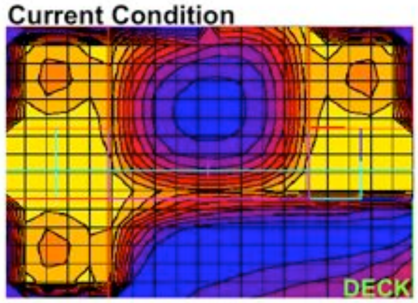
Hottest Day = April 23 at 1PM

**Notice the color differentiation in the bedrooms and living room

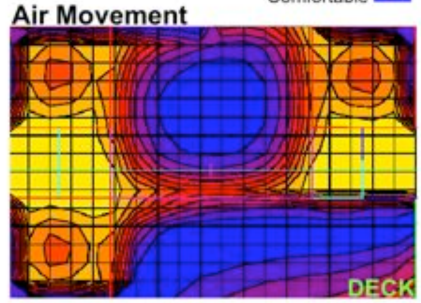
**No fans in bathrooms



Current Condition



Air Movement

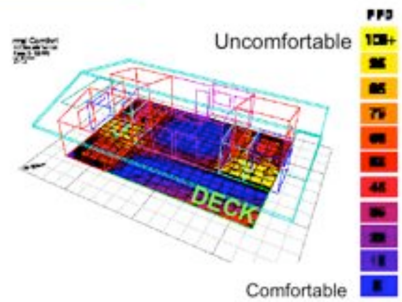


Results: % Dissatisfaction-Coolest Day

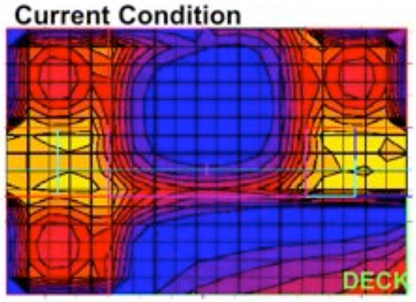
Coolest Day = Oct 22

**Notice the color differentiation in the bedrooms and living room

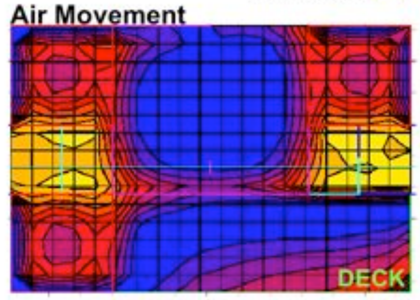
**No fans in bathrooms



Current Condition



Air Movement



Results: Ecotect Analysis Key Points

•Houses are consistently hot all year due to the humid, tropical climate.

•Without mechanical cooling systems to is difficult to *decrease* interior temperature.

•Although we are not decreasing temperature, we are increasing *comfort* by increasing air movement within the comfort range of people in French Polynesia

•Most appropriate idea is to introduce a hybrid system of natural ventilation and passive cooling methods (fan)

•Dark roofs are a major factor in contributing to increase in kit house temperature and needs to be analyzed.

•From our growing knowledge and understanding of Ecotect, we can easily manipulate design features based on actual kit house on site

Future Project Plans

1. Kit House Onsite

Envcoglobal.com

Monitoring Equipment

- Hobos: thermal sensors
- Flow analyzer: Used for watching air movement
- Digital Air Flow (humidity, temp, light level)
- Smart Dust: Embedded wireless sensoring network

Inhabitants: Polynesian Family or ourselves will be living in kit house

Ecotect Model

- After seeing/testing kit house, we can make model changes accordingly to analyze design features such as window placement, roof vent function etc

2. Survey

- Qualitative Survey on current comfort (people living in older prototypes)
- Semi structured interviews
- *Goal*: To produce post occupancy evaluation (POE) that can be used for quantitative research

Future Project Plans

3. **Building Information Modeling Programs**
    - Show OPH software
4. **Enable Distributer for products (Fan & Paint)**
    - Ace Hardware- have contacts
5. **Cost Analysis/ Testing of Infrared Reflective paint & clear gloss**
6. **Creating future networks for CE 290 class!**
7. **Detailed project proposal and budget**
8. **Possible work with LBNL**

Structural Goals

Overarching Goal

- Increase the environmental sustainability of the Moorea kit houses through application of structural design solutions

Immediate Goals

- Efficient timber framing
  - Stud/joist placement at 24" o.c. instead of either 12" or 16"

- Local material selection
  - Caribbean Pine vs. Douglas Fir

Approach

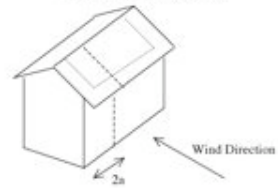
- Basic Wind Speed from coast of Florida (wind-borne debris region)
- Dead and live loads as specified in US Building Codes for 1-2 story timber framed buildings
- Design for ultimate minimum material requirements, then verify adequate behavior for members placed at 24" o.c.
- Use 2x lumber where possible to decrease material volume
- Design for both Douglas Fir and Caribbean Pine
- Use Southern Pine as substitute for Caribbean Pine material properties

http://www.kawneer.com/kawneer/north_america/en/product_info_page_cat.asp?cat_id=0&prod_id=0&parent_info_page_id=673&info_page_id=692

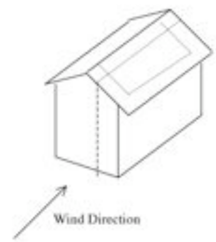
Approach

- Dead and Live loads applied at roof, ceiling, floor, and walls, as specified by code
  - Actual material weights not known
- Transverse Wind Load
  - Roof angle of 18º
- Longitudinal Wind Load
  - Roof angle of 0°
- Load Combinations
  - D + L + W
- Design for tension and compression
- Design for bending
- Design for combined tension/ compression and bending
- Determine total percentage of material volume decreased, if any

Transverse Loading



Longitudinal Loading



Results

- Roof
  - Tension force governs
    - Significant wind uplift without compressive weight
  - Independently, bending and tension requires limited amounts of timber
  - In combination, spacing members at 24" o.c. will be adequate for both Douglas Fir and Southern Pine
- External Walls
  - Tension force controls
  - Spacing at 24" o.c. ok for tension, bending, and combined forces
  - 24" o.c. maximum limit because of deflections of gypsum wallboard
- Design Specifications
  - Primary members 4x4, members required for spacing requirement 2x4
  - Reduces complexity of current design and varied sizes of timber ordered
  - Appropriate for developing timber industry in Moorea
- Material Reduction
  - 42 % of roof truss reduced, 39% of peak roof height material reduced, and 45% of external wall reduced
  - Total volume of material reduction: 43%

Concluding Thoughts and Reflections

•French Polynesia has extremely high living and property costs, yet income remains low, creating a demand/need for affordable housing

•It is essential that the Kit house is made as efficient as possible while keeping it comfortable and typhoon resistant.

•Working with OPH has the potential for large scale impact because small changes to house design and function will affect the entire importation and distribution process

•Ideally, the kit house will be locally produced and distributed

•Developed our own framework to work within the larger scope of the community as well as our continued research onsite

•We thought about our project as an overarching societal issue rather than just focus on the stated need.

•Acquired knowledge will help with our future research as well as the next CE 290 Moorea group!

Acknowledgements

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